

Special Issue

# *PV Thermal Systems: PV Panels Supplying Renewable Electricity and Heat*

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*With PV Thermal panels sunlight is converted into electricity and heat simultaneously. Per unit area the total efficiency of a PVT panel is higher than the sum of the efficiencies of separate PV panels and solar thermal collectors. During the last 20 years research into PVT techniques and concepts has been widespread, but rather scattered. This reflects the number of possible PVT concepts and the accompanying research and development problems, for which it is the general goal to optimise both electrical and thermal efficiency of a device simultaneously. The aspects that can be optimised are, amongst others, the spectral characteristics of the PV cell, its solar absorption and the internal heat transfer between cells and heat-collecting system. Another important level of optimisation is for the PVT device geometry and the integration into a system. The electricity and heat demand and the temperature level of the heat determine the choice for a certain system set-up. With an optimal design, PVT systems can supply buildings with 100% renewable electricity and heat in a more cost-effective manner than separate PV and solar thermal systems and thus contribute to the long-term international targets on implementation of renewable energy in the built environment. Copyright © 2004 John Wiley & Sons, Ltd.*

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## **INTRODUCTION**

PV panels absorb up to 80% of the solar irradiation. However, only 5–20% of the incident energy is converted into electricity, depending on the PV cell technology used. The remaining energy is converted into heat. Owing to this effect, on sunny days PV laminates can reach temperatures as high as 35°C above ambient temperature. In PV thermal (PVT) panels this heat is extracted from the PV panel and made available for use in a building, e.g., for tap water heating and space heating. In this way, the useful energy output of a PV panel is strongly enhanced.

Various mechanisms account for the conversion of irradiance into heat in PV laminates. The most important of these are related to the bandgap. In a solar cell only part of the incoming irradiation is converted into electricity, as indicated in Figure 1, due to two fundamental losses that occur in a single-junction cell. Photons with an energy smaller than the bandgap will not be absorbed by the active solar cell material. These photons may

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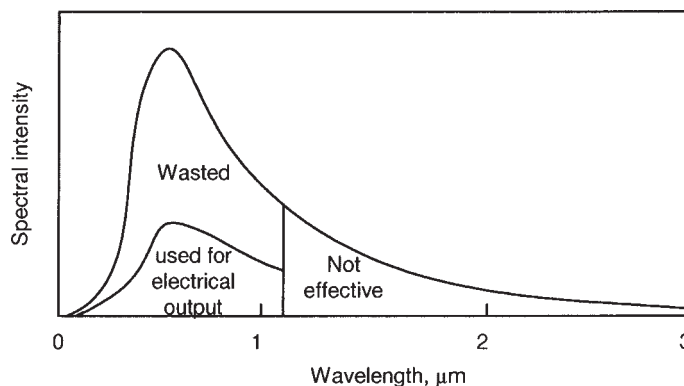


Figure 1. Sketch of the partition of the incoming sunlight converted to electricity or to heat, as a function of the wavelength

reach the back surface of the solar cell, will then be reflected to a great extent and will leave the solar cell at the front side. Only a small part of the photons will be absorbed at this back surface e.g., by the metallisation, and generate heat. Photons with an energy above the bandgap will generate only one electron–hole pair per photon. The excess energy, being the difference between the photon energy and the bandgap, will be transferred in the form of heat to the crystal lattice. In addition not all the energy transferred to the electron–hole pairs will be available as electricity, but part of it will be converted into heat among others by internal recombination and ohmic losses.

The reflection from PV cells is relatively large. This is due to the fact that in most cases the anti-reflection coating of solar cells is optimised for shorter wavelength in order to optimise the photocurrent. This implies that the reflection for longer wavelength can be significant, in contrast to the low reflection of spectrally selective coatings used in conventional thermal collectors, leading to a reduced thermal performance. This mechanism for increased reflection exists only for the cell area; for the spacing between the cells the absorption depends on the characteristics of the rear foil, which can be optimised to have a large absorption for all wavelengths.

Several types of PV thermal panels exist. The simplest type of a PVT panel is realised when an airflow is led along the rear of a conventional PV panel. The heated air can be used directly as ventilation air or used to transport the heat to a buffer. In a more advanced design, the PVT panel consists of a PV panel combined with a solar thermal absorber, as shown in Figure 2. Liquids can now also be used as the collector fluid. The solar thermal absorber transfers the heat to the collector fluid, which transports it to a heat storage or directly to the end user. This article is mainly devoted to advanced liquid PVT modules.

Two types of PVT liquid modules can now be discerned: uncovered PVT panels, as shown in Figure 2, and covered PVT collectors as shown in Figure 3. If the PVT panel from Figure 2 is built into a solar thermal collector casing the PVT collector like the one in Figure 3 is formed. The latter allows higher output temperatures, owing to the additional insulation from the transparent cover.

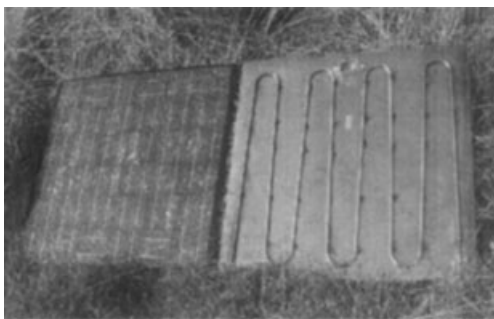


Figure 2. Uncovered PV thermal panel seen at the front (left) and at the rear side

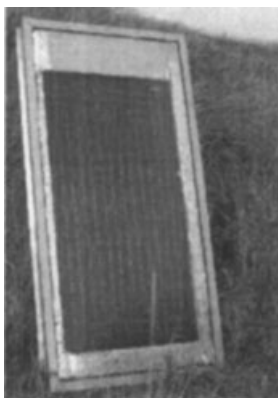


Figure 3. Prototype of a covered PVT collector

There are several reasons for the combination of PV and thermal into one device: larger overall conversion efficiency, reduced energy payback time, reduced economic payback time and improved aesthetics.

1. System calculations have been carried out, indicating that for a domestic hot water system with 1 m<sup>2</sup> of solar thermal collector and 1 m<sup>2</sup> of PV would together yield 520 kWh thermal and 72 kWh electrical energy annually, whereas 2 m<sup>2</sup> of PV thermal collector would yield 700 kWh thermal and 132 kWh electrical.<sup>1</sup> The higher average yield per m<sup>2</sup> is especially relevant if there is competition on the roof, a phenomenon that can be observed for houses in Japan, and for apartment buildings in countries such as the Netherlands. By using PVT, a higher share of renewables can therefore be realised in the built environment, which is in accordance with the targets set for renewables by the EU as part of the global effort to decrease the use of fossil fuel.
2. Energy payback calculations have been carried out indicating that the energy payback time of a PV thermal system under the Italian climate would be 2 yr, compared with 4.3 yr for a solar thermal collector and 3.4 yr for a PV system.<sup>2</sup>
3. Since the extraction of heat can be realised at relatively low cost, the economic payback time is shortened in comparison to conventional PV panels. An economic analysis of PVT solar system for domestic hot water, compared with PV laminates, was carried out for the Greek climate.<sup>3</sup> The study indicated that the payback time for a PV system was 25 years for c-Si and 29 years for a-Si, whereas for PV thermal systems these payback times were shortened to 10 and 6 yr, respectively. For a conventional solar thermal system, a payback time of 3 yr was found. The payback time is not only shortened by the additional yield, but also by lower installation costs, reduced use of BOS components and cost reductions, e.g., in the edge finish.
4. With respect to aesthetics, architects and consumers prefer a uniform PVT roof area to a roof area partially covered with thermal collectors and partially with PV laminates. Secondly, PVT panels have the same external appearance as PV panels, which many consumers consider to be more appealing than solar thermal collectors.

## PVT RESEARCH AND DEVELOPMENT SO FAR

The first systematic research into the possibilities of combining photovoltaic and solar thermal techniques was performed in the early 1980s by a group at MIT.<sup>4</sup> In this comprehensive study, several PVT designs were made and tested, both air-type and water-type. The work was discontinued because of a change in government funding.

The PVT research regained attention in the mid 1990s with, amongst others, the PhD work of De Vries at the Eindhoven University of Technology.<sup>5</sup> He designed several PVT module concepts, of which one was realised and tested. A numerical model was developed calculating both electrical and thermal performance. The model predictions were found to agree with the experimental results.<sup>1</sup> The work was continued with a development

programme at the Energy research Centre of the Netherlands ECN.<sup>6</sup> In collaboration with industry and the EUT the thermal performance was further optimised and a production technology was developed.<sup>7</sup> Bakker investigated another PVT concept, a two-absorber module, at ECN.<sup>8</sup>

In recent years, several other research groups worked on the topic of PVT. At the University of Patras in Greece, a broad range of PVT geometries for PVT panels were designed, built and tested.<sup>9</sup> PhD research on a PVT design with a concentrating reflector is being performed in Sweden.<sup>10</sup> In Norway, a concept is developed in which a plastic thermal absorber is used.<sup>11</sup> Work on the application of thin-film PV in PVT concepts was carried out in Switzerland.<sup>12,13</sup>

From a more complete overview of the literature on PVT collectors<sup>14</sup> it can be concluded that the research and development activities on PVT are widespread over the world and conducted in relatively small programs. Owing to this dispersion there was little attention for PVT from the PV R&D community. As a result the PVT development had to restrict itself to the application of market-ready PV technologies.

## PVT SYSTEM CONCEPTS

The use of heat in buildings can roughly be divided into two main areas. First, heat is used to keep the interior temperature at a comfortable level in cold seasons. The required amount of heat is dependent on the ambient temperature and on the thermophysical properties of the building while the required temperature depends on the characteristics of the heating system. Older buildings with a central heating system need temperatures of 70–90°C to sustain proper interior temperatures. In modern buildings with good thermal insulation and high-efficiency glazing, however, low-temperature heating systems can be applied which require temperatures of the order of 30–40°C, even in cold climates.

The second main utilisation of heat in buildings is for hot tap water. The temperatures needed for heating tap water are around 60°C.

In PVT panels the solar energy is converted into heat in the same way as in conventional solar thermal collectors. The actual conversion takes place in the absorber. Figure 4 gives a sketch of a solar thermal collector, with the main energy flows.

Part of the heat generated in the absorber is lost either by radiation or by convection to the surroundings. If the hot absorber is in direct contact with the surroundings, as is the case in so-called uncovered collectors and PVT

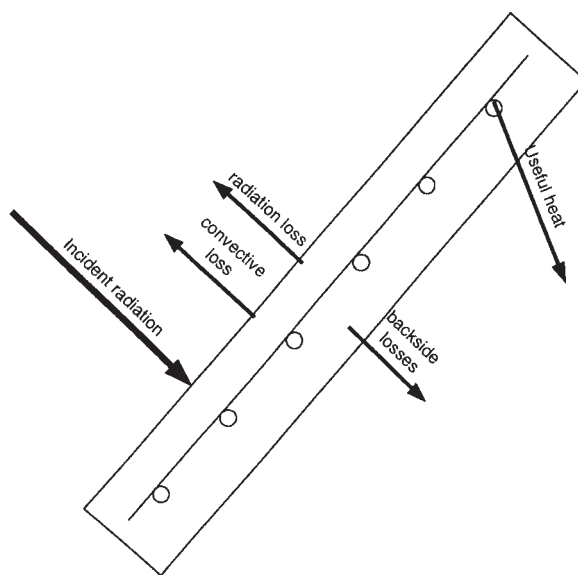


Figure 4. Schematic of the energy flows in a solar thermal collector

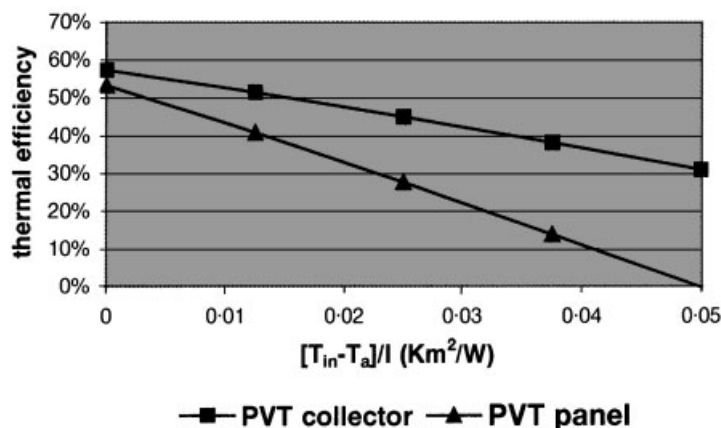


Figure 5. Typical thermal efficiency curves for covered PVT (squares) and uncovered PVT (triangles)

panels, the heat loss is considerable and the temperatures that can be reached with acceptable efficiency are relatively low, closer to the ambient temperature. Uncovered collectors and PVT panels are therefore better fit to serve low-temperature heating applications or LT systems, generally driven by heat pumps.

In standard solar thermal collectors and covered PVT collectors, a transparent cover is placed above the absorber. The cover transmits about 90% of the incident solar radiation, depending on the material used. This reduction in irradiation is for most applications less important than the thermal insulating effect of the cover, leading to a substantial increase in thermal efficiency.

Figure 5 shows some typical thermal efficiency curves for covered and uncovered PVT. As is normal in solar thermal practice, the collector efficiency is plotted versus  $T^*$ , the difference between fluid inlet temperature and ambient temperature, divided by the incident solar radiation:

$$T^* = (T_{in} - T_A)/I$$

The slope of the efficiency curve is a direct measure of the thermal loss coefficient. It can be seen that the uncovered collector has a higher thermal loss than the covered collector. In the situation of the inlet fluid temperature being equal to the ambient temperature (when  $T^* = 0$ ) the efficiency is equal to the so-called zero efficiency. This is the product of the cover's total transmittance and the absorption coefficient of the absorber (the optical efficiency), multiplied by a factor representing the non-ideal temperature distribution over the absorber surface.

The thermal efficiency is directly dependent on the collector fluid inlet temperature, which in turn depends on the dynamics of the rest of the thermal system. This means that the same collector connected to different thermal systems can give completely different average collector efficiencies. From another point of view, therefore, if the collector characteristics fit the demands imposed by the system, an optimal efficiency is obtained. Next we will give two examples of thermal systems in which PVT can be integrated.

## LT SYSTEM WITH HEAT PUMP

As we have seen in Figure 5 an uncovered PVT panel has a higher heat loss to the surroundings, owing to the lack of a transparent cover. As the thermal efficiency is better near ambient temperature, the choice for lower system working temperatures leads to higher annual efficiencies. If an array of PVT panels is connected to a seasonal heat store, for instance an earth-coupled heat exchanger, the low-temperature heat gained in the summer is stored in the ground and used in the winter. The system configuration is sketched in Figure 6. A heat pump upgrades the low-temperature heat to higher temperatures fit for either room heating or for hot tap water.

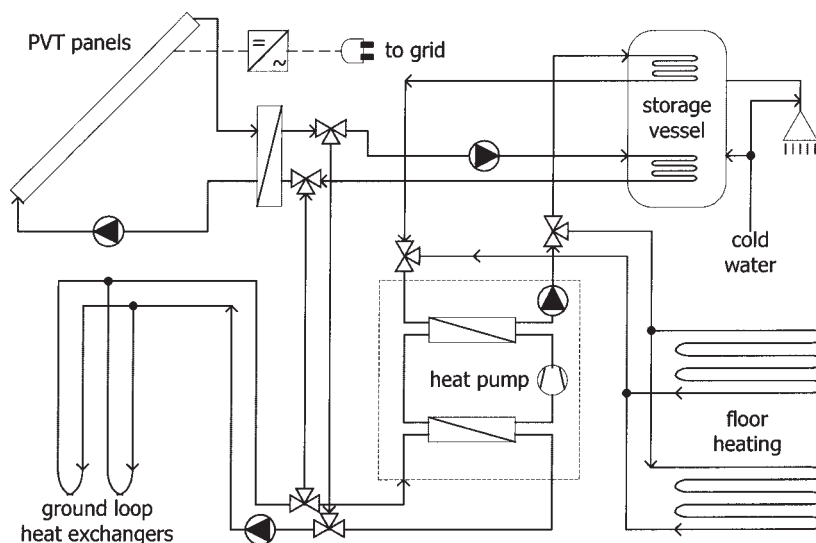


Figure 6. Schematic of a PVT system as a source for a heat pump, providing both room heating and hot water. A vertical soil heat exchanger is used as seasonal heat storage

The PVT panels provide for the electricity demand of the heat pump. With this configuration a solar fraction of 100% is easily reached: the sun provides all the heat and electricity.

## SOLAR DOMESTIC HOT WATER (SDHW) SYSTEMS

PVT collectors, having a transparent cover, can produce medium temperature heat and are therefore similar to normal solar thermal collectors with respect to system applications. Figure 7 shows the set-up of a solar domestic hot water system (SDHW) with PVT collectors. The PVT array with an area of  $6 \text{ m}^2$  generates heat that is stored in a thermally isolated water tank of 200 l. If 120 l hot tap water at  $60^\circ\text{C}$  is withdrawn daily the system contributes 5.0 GJ of solar heat to tap water heating annually, resulting in a solar fraction of 47% and a thermal system efficiency of 22%. The electrical efficiency is reduced to 90% (or more, depending on the system configuration) of the rated efficiency at standard operating conditions, caused by the reduced light transmission due to the extra transparent cover and by the higher mean operating temperature of the PVT collector.<sup>15</sup>

The system efficiency is comparable to that of a system with  $4 \text{ m}^2$  solar thermal collectors. Typical working temperatures are in the range  $60\text{--}80^\circ\text{C}$ . Owing to the reduced heat loss, however, the maximum temperatures of

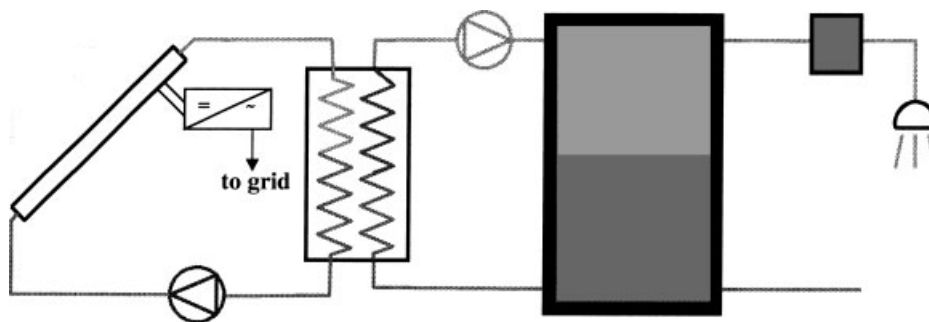


Figure 7. Schematic of a PVT system for domestic hot water preparation

covered PVT collectors can be much higher than those of uncovered PVT panels. This puts constraints to the materials and techniques that can be applied in PVT collectors.

The different system concepts result in different demands and constraints on the PVT concepts. There are two levels on which the PVT technology can be altered and optimised to the specific applications. The first optimisation can be performed at the device level, by choosing alternative PV technologies, other materials or production technologies. The second possibility for optimisation is in the choice of different geometries or module concepts.

## OPTIMISATION ON A DEVICE LEVEL

Every system configuration generates a typical set of criteria for the optimal PVT functionality. If a choice has been made for a PVT module concept, the electrical and thermal efficiencies can be optimised by selection and optimisation of the solar cell technology, of the materials and of the production technologies. The possible research and development work is described and discussed in the following.

### *Emission of heat*

The two main mechanisms for heat loss in a solar thermal device are loss by convection and by radiation. Transparent covers can reduce the convection heat loss. The only way to prevent radiation heat loss is to coat the surface of the hot absorber with a material that has a low emissivity for infrared radiation. In solar thermal collectors this is done by so-called spectrally selective coatings. These combine a high absorption of the visible part of the solar spectrum with a low emissivity in the infrared. Spectrally selective coatings are applicable in PVT devices only if they have a high transparency of the visible region, to maintain the electrical efficiency of the PV cells. In practice, coatings like this are already applied as low-emission coatings in high-efficiency double glazing-systems, but with a transparency of the order of 60–80% which is too low for application in PVT. Further research into new materials for these selective coatings is necessary.

### *Solar absorption*

Looking at the front side of a photovoltaic module one can distinguish basically three types of area: the active area of the cells, the metallisation of the cells with interconnecting metallisation and the area between and/or around the cells. The effective solar absorption factor is the weighted average of the individual areas. The division of the various surface areas and the resulting absorption factor is given in Table I for a typical geometry of a PV panel with multicrystalline silicon solar cells.

The effective solar absorption factor can be increased in several ways. The largest gain can probably be achieved by an improvement of the active area absorption factor of the solar cells. Semiconductors, such as crystalline silicon, which are used as active material in solar cells absorb only part of the solar spectrum. The photon energy needs to be at least the bandgap energy  $\Delta E_g$  of the semiconductor (1.1 eV in the case of crystalline silicon). Photons with an energy slightly above  $\Delta E_g$  (1.1–1.4 eV in the case of crystalline silicon) are only partly absorbed, implying that part of the photons will leave the solar cell at the front after being reflected at the back surface of the cell. Optical confinement by, for instance, the application of texturisation and/or a diffuse back reflector can enhance the absorption factor, which is favourable for both the electrical and the thermal efficiency. Texturisation can be achieved by chemical etching and results in a roughened surface.

Table I. Distribution of PV surface area and corresponding absorption factors<sup>4</sup>

Material	PV cells active area	Metallisation	Cell spacing + side spacing	Total
Area (m <sup>2</sup> )	0.65	0.07	0.15	0.87
Absorption factor $\alpha$	0.81	0.48	0.77	0.78



Table II. Material thermal properties and measured resulting heat transfer coefficient for two different bonding techniques

Bonding technique	Heat conductivity of material (W/mK)	Material thickness (mm)	Measured resulting heat transfer $h_{ca}$ ( $\text{W m}^{-2}\text{K}^{-1}$ )
Gluings (epoxy with Al oxide) of prelaminated PV panel	0.85	0.15	100
Direct lamination on copper absorber (EVA)	0.35	1	125

Such a surface provides higher internal reflection for light within the cell because of an increase of the mean incident angle.

The metallisation has a high reflection coefficient. There are two ways to increase the absorption factor of the metallisation: reduction of the area used for metallisation and enhancement of the absorption factor of the conductors applied by the use of suitable coatings. In case of crystalline silicon the metallisation basically consists of two parts: the finger current collection system and a busbar system. The typical active area of today's crystalline silicon solar cells is 91% of the total cell area. Of the 9% loss, 4% is caused by the busbar system. By cell concepts such as EWT (emitted wrapped through) and the ECN PUM (pin-up module) the busbars are transferred to the back-surface of the cell and an active area of 94–95% can be achieved.<sup>16</sup> An active area gain of 1–2% can be obtained by Green's LGBC (laser grooved buried contact) concept.<sup>17</sup> For many thin-film PV technologies the reflection of top metallisation is very low, when transparent conductive oxides are used.

The material at the back of the laminate absorbs the solar irradiation falling onto the area between and around the cells. By increasing the solar absorption factor of this material, the total absorption can be enhanced. The use of a dark back sheet, however, will slightly reduce the amount of light coupled into the cell edge and will reduce the electrical output slightly.

### *Internal heat transfer*

In many PVT concepts, the generation and the removal of heat takes place in different locations in the module. For an optimal thermal yield the materials between these locations should have good thermal conductivity properties. In the basic concept PVT (see Figure 9) good thermal conductivity leads to a small temperature difference between the PV cells and the heat-transporting fluid in the tubes and thus to a minimal cell temperature. The total heat transfer coefficient  $h_{ca}$  between PV cells and plate is mainly determined by the conductivity of the intermediate layers, as both silicon and copper have a relatively high conductivity. Table II gives  $h_{ca}$  for two different bonding techniques.

### *PVT module reliability*

At first sight, one might expect that the reliability of PVT devices is similar to that of the solar thermal collector and a PV panel. However, this does not take into account the severe conditions to which materials in a PVT device are subjected.

First of all, the materials that are applied in a covered PVT collector experience substantially higher temperatures than in conventional PV panels. This is especially true if the heat is not withdrawn from the PVT collector, e.g., due to pump failure. Temperatures of up to 126°C have been measured under such conditions in a prototype PVT collector in the Dutch climate (Figure 8). Such high temperatures set high demands on the temperature resistance of the plastic layers in the PV laminate, including the encapsulant. If the temperature resistance of the encapsulant is insufficient, deterioration may result. In addition, owing to the high temperatures, the UV resistance is reduced, which may lead to yellowing.

Secondly, large thermal stresses may occur if, on a sunny day around noon, a collector is switched on and cold water is suddenly flowing into a hot collector. Temperature differences of over 100°C may then occur between collector fluid and PV laminate, causing a fast and inhomogeneous thermal contraction. The complete device should be able to cope with these stresses.



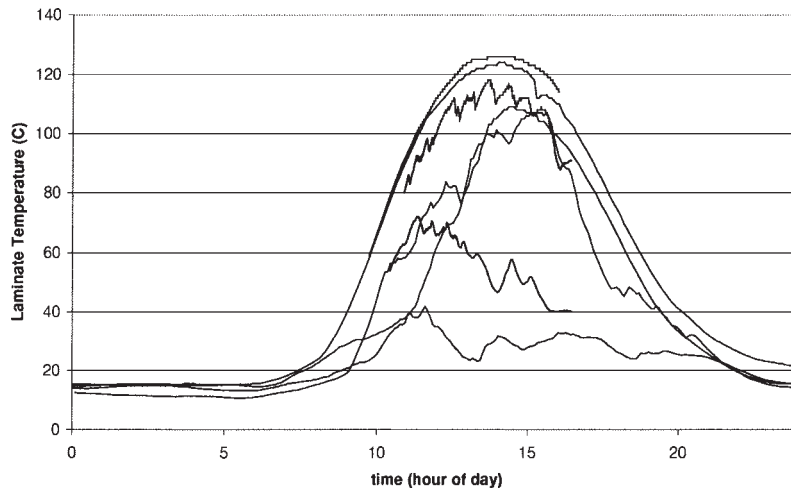


Figure 8. Measured stagnation temperature of a covered PVT collector during various days in the Netherlands, May–August 2002 ( $T_a$  14–30°C,  $v_{wind}$  1–8 m/s)

Finally, the electrical conductance of the metal sheet in a PVT module consisting of a metal sheet-and-tube construction may cause problems. The large electrical conductivity leads to additional demands on the electrical insulation between PV cells and metal rear, especially the electrical contacts.

The R&D needed to address all these aspects range from fundamental materials research in the case of the minimisation of heat emission and optimisation of solar absorption, to production technology development in the case of the internal heat transfer optimisation and the module reliability aspects. A lot of the optimisation problems on a device level depend on the choice of the PVT concept, however. Some of the possible PVT module concepts are described in the following.

### OPTIMISATION ON MODULE CONCEPT LEVEL

Part of the solar spectrum does not contribute to the electricity production in a photovoltaic solar cell. Photons with an energy lower than the bandgap do not have enough energy to create photon–hole pairs and could in principle fully contribute to the generation of heat. This generation can take place either in the cell or outside the cell if the cell material does not absorb light at these wavelengths. The position of heat generation in the device determines the possible PVT device geometries. In most concepts all heat is generated in one place in the device. In a two-absorber PVT collector, however, part of the heat is generated outside the PV cells.

In Figure 9, the basic PVT concept is shown. The heat generated in the PV cells is collected by a standard sheet-and-tube geometry. The heat-conducting properties of the connecting layer between the PV cells and the

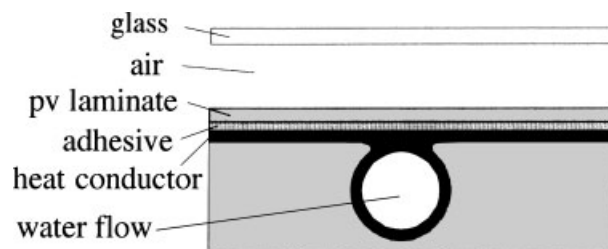


Figure 9. Basic PVT concept. A PV laminate and a sheet and tube solar thermal absorber are connected to each other either by gluing or by lamination

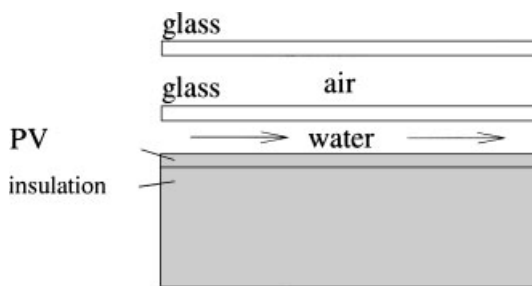


Figure 10. Channel PVT concept. The heat generated in the PV cell is removed by liquid flowing on top of the PV laminate

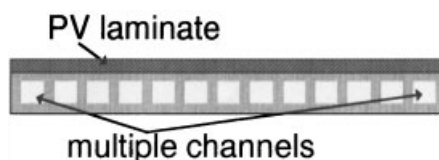


Figure 11. Channel PVT concept with liquid flow beneath the PV cells

sheet determine the thermal efficiency for a substantial part. Prototypes of this PVT concept used a glue layer with high thermal conductance, later the technique of direct lamination was developed.<sup>7</sup>

A more effective heat transfer is obtained when the mean distance between heat generation and heat collection is minimal. This is the case when the liquid flows over the complete area of the PV cells. If the liquid flows on top, the channel PVT concept as depicted in Figure 10 is realised. If the heat is drawn off from beneath the PV cells the resulting concept is depicted in Figure 11.

An alternative for the water channel in Figure 10 is to use a channel plate at the rear of the PV. The channels in Figure 11 are multiple channels formed in a plastic sheet by extrusion. This geometry is better suited to withstand water pressures in the channels than in the case of one broad channel in Figure 10. Plastics, however, have a relatively large coefficient of thermal expansion. This makes a reliable connection between channel material and PV cells rather difficult to produce.

If the PV cells can be made transparent, either through the use of gridded back contacts or by interspaced cells, a two-absorber geometry can be applied, as sketched in Figure 12. A main advantage of this concept is that a lower mean PV cell temperature is maintained, compared with geometries with heat and electricity generation in one plane. A disadvantage, however, is the complexity of the geometry, making the module difficult to manufacture.

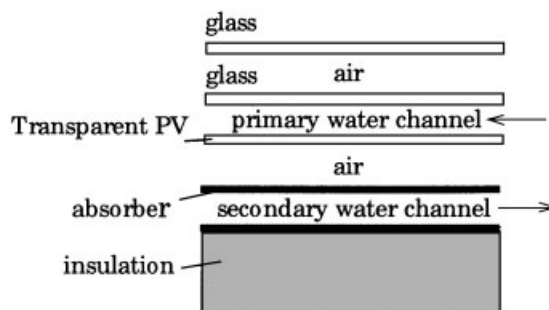


Figure 12. Two-absorber PVT concept. Part of the incident light is transmitted by the PV cells and converted to heat by a secondary absorber. The liquid flows first along the PV laminate, collecting its heat, and then along the secondary absorber

## PVT MARKETS

Presently, only PV thermal air systems are commercially available (e.g., from the German company, Grammer and the Canadian company, Solarwall). For PVT liquid systems, several manufacturers have tried to develop a PV thermal module, but this has not led to large-scale commercial manufacturing of these collectors.

In Germany there have been three initiatives for PVT collectors. Solarwatt introduced the so-called Multi-solar system, using multicrystalline silicon PV cells. Zenith used a triple junction PV panel of Uni-Solar to build a PVT collector.<sup>18</sup> Solarwerk announced its so-called Spectrum, with mono-crystalline silicon cells on an aluminium absorber.<sup>19</sup> The Israeli company Solor introduced PVT systems on the market with 18 demonstration systems.<sup>20</sup> The systems produce electricity, hot air and hot water.

These initiatives never led to real market introduction programmes for PVT liquid systems. Several reasons can be brought up to explain this. First, very little has been published on PVT system and production technology, indicating that this area has scarcely been investigated. Secondly, there is very little experience with PVT products. Good market research is necessary, especially as PVT combines aspects of both PV and of solar thermal and these two market fields are quite different. A third reason could be that many of the companies that were involved in the PVT initiatives were taken over by companies that did not place PVT in their product range.

Since PVT is a combination of PV and solar thermal, it can be used in the overlapping segments of both markets. Since PV has much wider potential application than solar thermal, the PVT market is largely equal to the solar thermal market. This is mainly the domestic market with its continuous demand for hot tap water. The perspectives for the office market are less since most offices have a low heating demand.

In the year 2001, the annually installed area of solar collectors in Europe<sup>21</sup> was  $1.4 \times 10^6 \text{ m}^2$ , with a total area of  $11 \times 10^6 \text{ m}^2$ . Presently, the market for glazed collectors consists largely of systems for tap water heating, while a growing share of the market consists of combi-systems for tap water and space heating. It is expected that the majority of this market is also suitable for PVT.

From a European perspective, in the white paper 'Energy for the Future', the projected share of solar thermal for 2010 is 100 million  $\text{m}^2$  and for PV this is 3  $\text{GW}_p$ . With respect to both markets, this requires a substantial increase of the annually installed area. The large-scale introduction of PVT could help to reach this goal. The importance of PVT on a macro-economic scale is illustrated by the following simple calculation. The electrical power of  $1 \text{ m}^2$  of PVT can be roughly taken to be  $80 \text{ W}_p$ . To achieve in the EU target for PV, an area of  $37.5 \times 10^6 \text{ m}^2$  PVT is sufficient. This is less than 40% of the EU solar thermal target. With PVT, the targets are achievable with less material and manpower and thus with a lower budget.

## CONCLUSIONS

PVT modules convert sunlight into electricity and heat simultaneously. Their total efficiency is higher than the sum of the efficiencies of separate PV and solar thermal systems. In the case of a limited available roof area PVT offers a more cost-effective alternative. Moreover, through the higher combined yield PVT can contribute to the reduction in the consumption of fossil fuels in the built environment in a more cost-effective way.

The available roof area, the respective demands of electricity and heat and the demanded temperature level of the heat determine the PVT system set-up that is most suited for a given house or building. The same boundary conditions determine the optimal PVT concept for a given system configuration. To arrive at optimal concepts, challenging research and development efforts have to be performed in a broad range of topics. This, and good cooperation between the various research groups is a prerequisite for a successful market introduction of PVT. The large-scale introduction of PVT could help to achieve the international goals for PV and solar thermal installations in the future, at lower costs.

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